Interaction Region Design of MEIC at JLAB

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Workshop on EIC Detector R&D Simulations
BNL, October 9, 2012

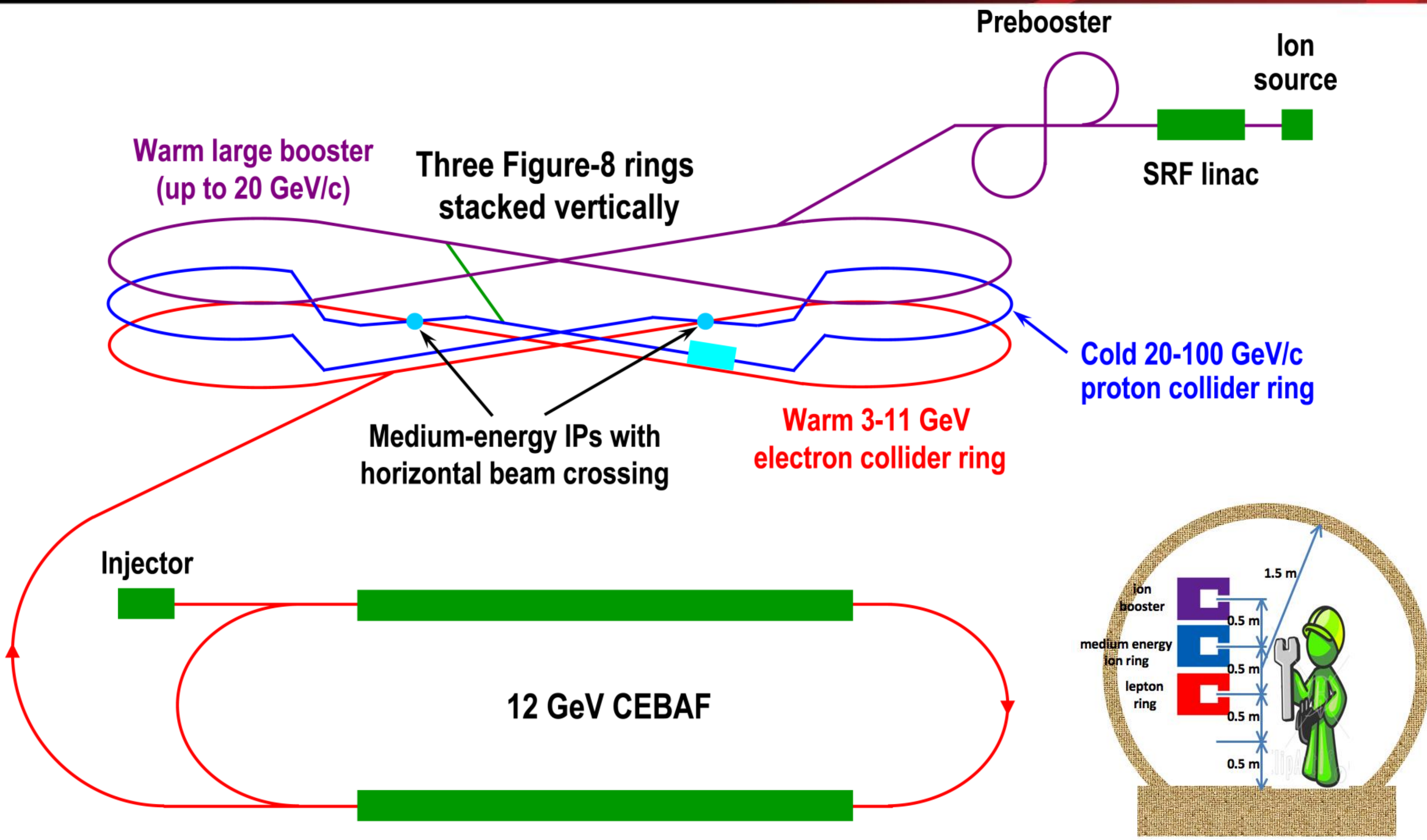
Outline

- Introduction of MEIC
- IR design considerations and features
  - Detector-optimized IR optics
  - Crab crossing scheme
  - Chromaticity compensation concept
  - Momentum acceptance and dynamic aperture
- Outlook

MEIC Design Parameters

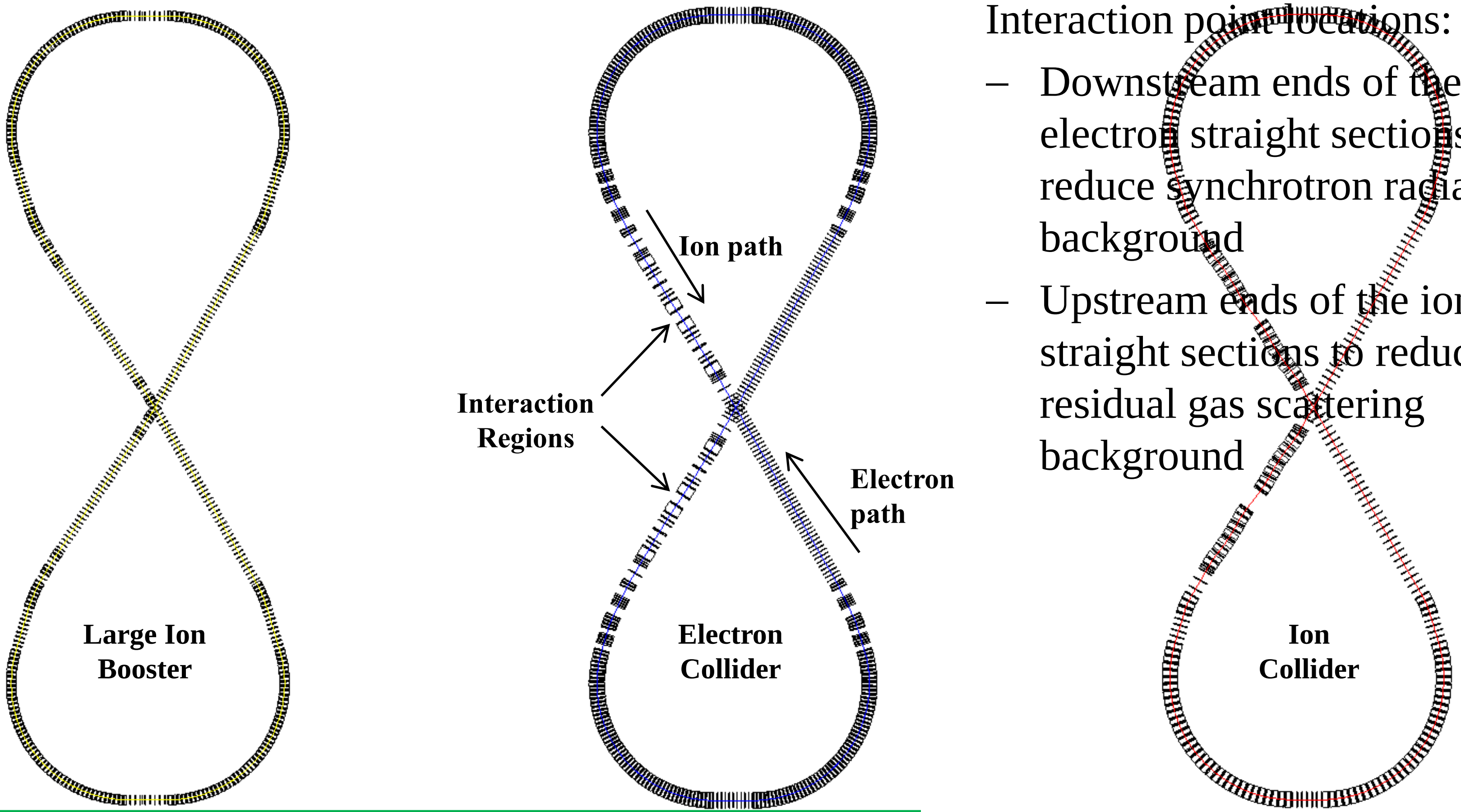
- **Energy** *(bridging the gap of 12 GeV CEBAF & HERA/LHeC)*
  - Full coverage of *s* from a few 100 to a few 1000 GeV^2
  - Electrons 3-11 GeV, protons 20-100 GeV, ions 12-40 GeV/u
- **Ion species**
  - Polarized light ions: p, d, ^{3}He, and possibly Li, and polarized heavier ions
  - Un-polarized light to heavy ions up to A above 200 (Au, Pb)
- **Up to 3 detectors**
  - One optimized for full acceptance, another for high luminosity
- **Luminosity**
  - Greater than $10^{34}\ \text{cm}^{-2}\text{s}^{-1}$ per interaction point
  - Maximum luminosity should optimally be around $\sqrt{s}$=45 GeV
- **Polarization**
  - At IP: longitudinal for both beams, transverse for ions only
  - All polarizations >70% desirable
- **Upgradeable to higher energies and luminosity**
  - 20 GeV electron, 250 GeV proton, and 100 GeV/u ion

MEIC Layout



Cross sections of tunnels for MEIC

Stacked Figure-8 Rings



Interaction point locations:

– Downstream ends of the electron straight sections to reduce synchrotron radiation background
– Upstream ends of the ion straight sections to reduce residual gas scattering background

- Vertical stacking for identical ring circumferences
- Horizontal crab crossing at IPs due to flat colliding beams
- Ion beams execute vertical excursion to the plane of the electron orbit for enabling a horizontal crossing, avoiding electron synchrotron radiation and emittance degradation

- **Ring circumference: 1340 m**
- **Maximum ring separation: 4 m**
- **Figure-8 crossing angle: 60 deg.**

Parameters for ***Full Acceptance*** Interaction Point

		Proton	Electron
Beam energy	GeV	60	5
Collision frequency	MHz	750	750
Particles per bunch	10^{10}	0.416	2.5
Beam Current	A	0.5	3
Polarization	%	> 70	~ 80
Energy spread	10^{-4}	~ 3	7.1
RMS bunch length	mm	10	7.5
Horizontal emittance, normalized	µm rad	0.35	54
Vertical emittance, normalized	µm rad	0.07	11
Horizontal β*	cm	10	10
Vertical β*	cm	2	2
Vertical beam-beam tune shift		0.014	0.03
Laslett tune shift		0.06	Very small
Distance from IP to 1st FF quad	m	7	3
Luminosity per IP, 10^{33}	$cm^{-2}s^{-1}$	5.6	

Design Features: High Polarization

- All ion rings (two booster, collider) have a figure-8 shape
  - Spin precessions in the left & right parts of the ring are exactly cancelled
  - Net spin precession (spin tune) is zero, thus energy independent
  - Ensures spin preservation and ease of spin manipulation
  - Avoids energy-dependent spin sensitivity for ion all species
  - <u>The only practical way to accommodate polarized deuterons</u>

This design feature promises a high polarization for all light ion beams, and supports acceleration of polarized heavier ions.

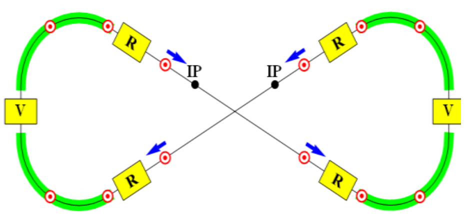
(The electron ring has a similar shape since it shares a tunnel with the ion collider ring)

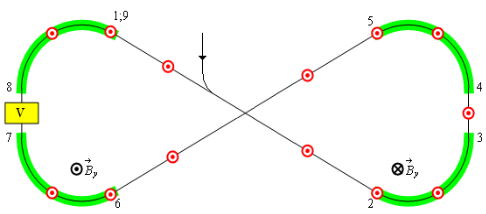
- Use small fields (instead of Siberian Snakes) to control the beam polarization at IPs

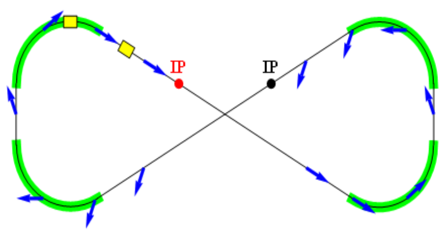
Proton or Helium-3: longitudinal polarization at both IPs

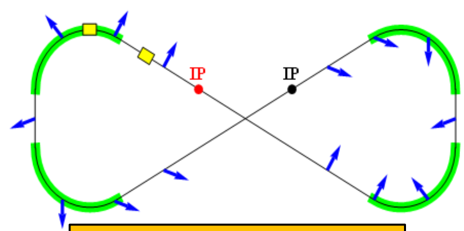
Proton or Helium-3, Deuteron: transverse polarization at both IPs

Deuteron: Longitudinal and radial polarization at one (each) IP







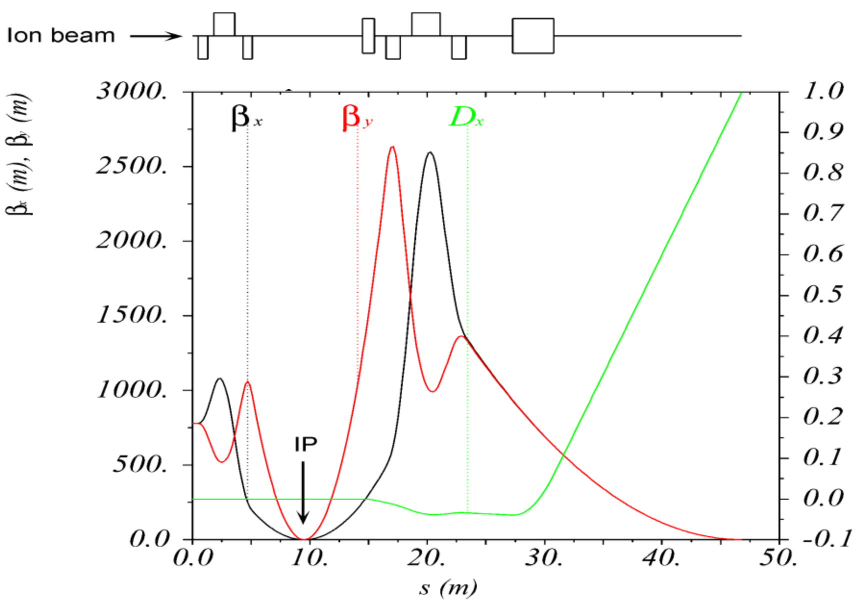


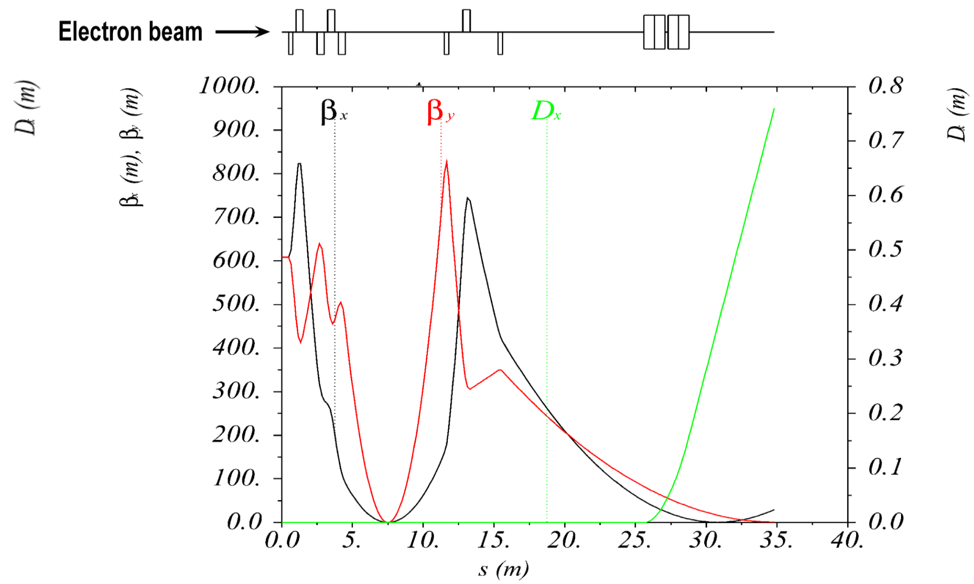
A.M. Kondratenko

IR Design Considerations and Features

- Large detector space (7m) for a full-acceptance detector
- Detection of forward scattered hadrons down to 0°
  - Large aperture downstream ion final focusing quadrupoles
  - Large machine-element-free drift space after large spectrometer dipole
  - Secondary focus after large spectrometer dipole combined with large dispersion for better momentum resolution
- Detection of low-Q^2 electrons and electron momentum analysis
- Large 50 mrad crab crossing angle for faster beam separation (to reduce parasitic collisions due to high repetition rate and increase space for magnets) and better detector resolution
- IPs close to exit from ion arcs (reduce residual gas scattering background) and far from exit from electron arcs (reduce synchrotron radiation background)
- Vertical ion chicane to avoid electron synchrotron radiation and emittance degradation
- Compatibility with crab crossing to restore head-on collisions
- Small β^* for high luminosity
- Different β^*_x and β^*_y for a more balanced optics design
- Large momentum acceptance and dynamic aperture
  - Symmetric chromaticity compensation scheme
  - Asymmetric detector space (upstream ion final focusing block moved closer to the IP)
- Use permanent-magnet design for some of the electron final focusing quadrupoles to move them closer to the IP without reducing detector solid angle coverage

Detector-Optimized Optics



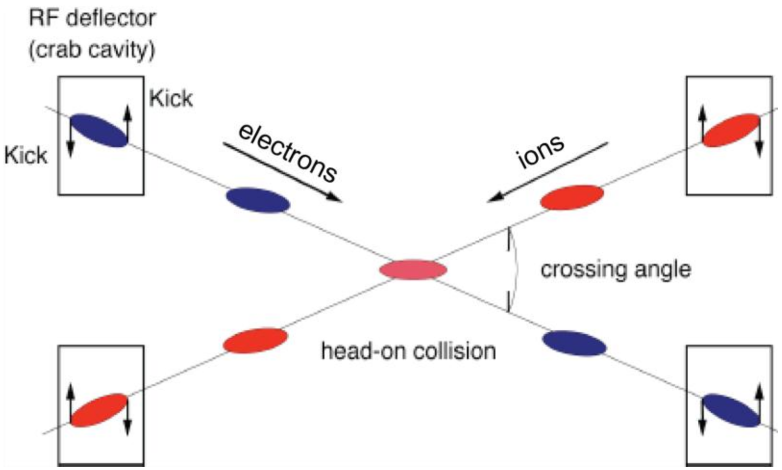


- Upstream FFB is placed much closer to the IP than that on the downstream
  - Upstream FFB reduces the maximum betatron functions and the contribution to the chromaticity
  - Downstream FFB was designed to have larger apertures of its quadrupole, plus increasing distance from the IP, to maximize its acceptance to the forward-scattered hadrons
- Further focusing in the downstream (small beam size) allows to place the detectors close to the beam center. Combining with ~1m dispersion at the focal point, it can detect particles with small momentum offset Δp/p

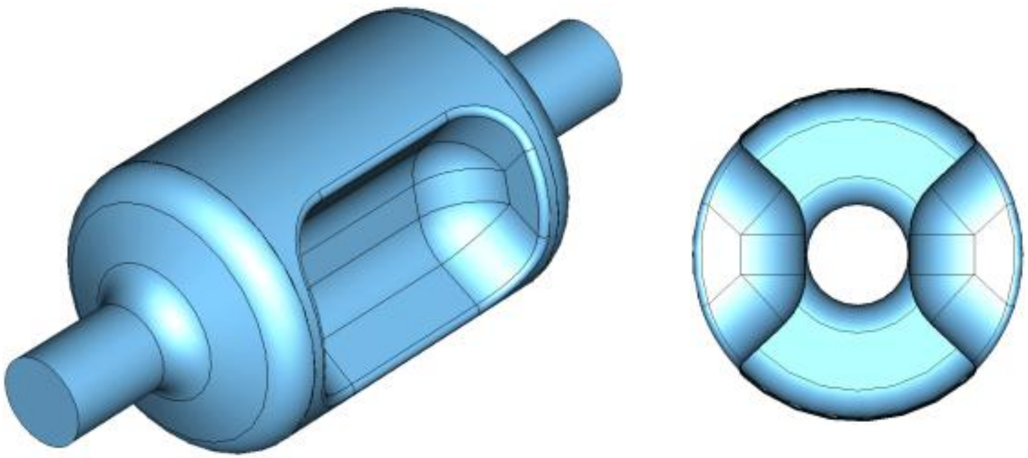
- Similar optics
- In addition, two permanent magnetic quadrupoles are used in the upstream FFB and vey close to the IP to maximize the ion detector acceptance by reducing the solid angle blocked by the final focusing quadrupoles. Changing of their focusing strengths with energy can be compensated by adjusting the upstream electric quadruples.

Crab Crossing Scheme

- Restore effective head-on bunch collisions with 50 mrad crossing angle $\Rightarrow$ Preserve luminosity
- Dispersive crabbing (regular accelerating / bunching cavities in dispersive region) vs. Deflecting crabbing (novel TEM-type SRF cavity at ODU/JLab, very promising!)
- Compensation scheme for crab crossing
  - Global: (KEK B-Factory) only one cavity installed in each collider ring
  - Local: (MEIC) two identical crab cavities, one for crabbing and the other for restoration. The two crab cavities are placed in the locations, which ensure phase advance (n+1)π/2 relative to IP to minimize the required integrated crab kicking voltage and confine the beam gymnastics only in the IR.

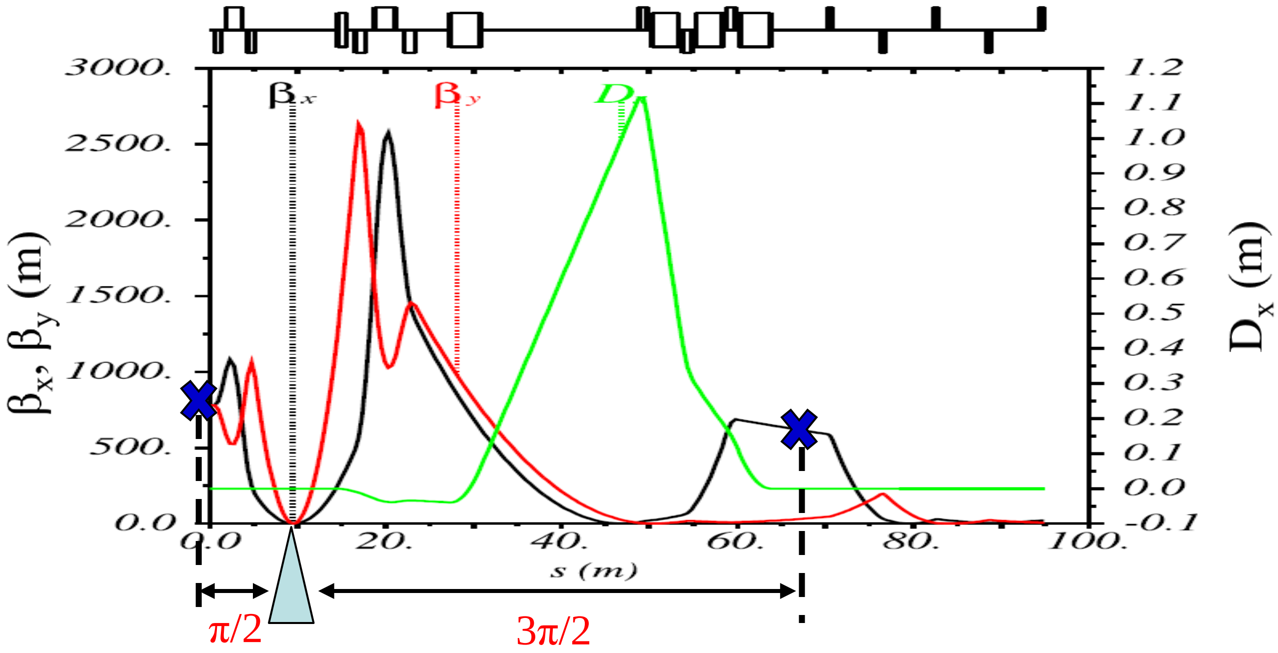


MEIC crab cavity design



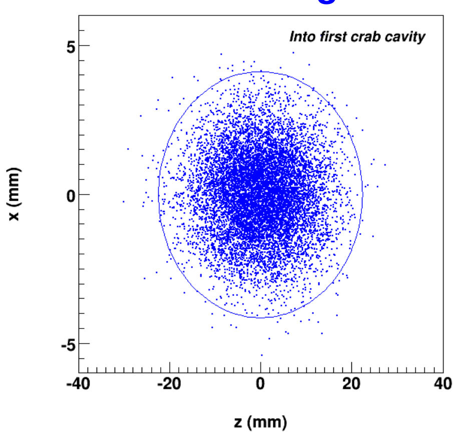
Crab Crossing Scheme

- Linear Optics
  - Two cavities are placed to ensure phase advance (n+1) π/2 relative to IP.
  - Two cavities are placed at those locations with relatively large β_x to reduce the required crab kicking voltage.

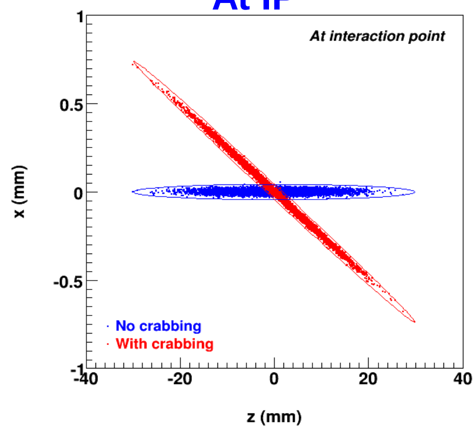


- Tracking Simulations

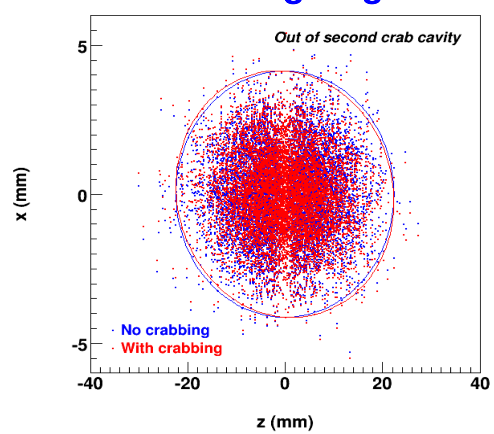
Incoming



At IP

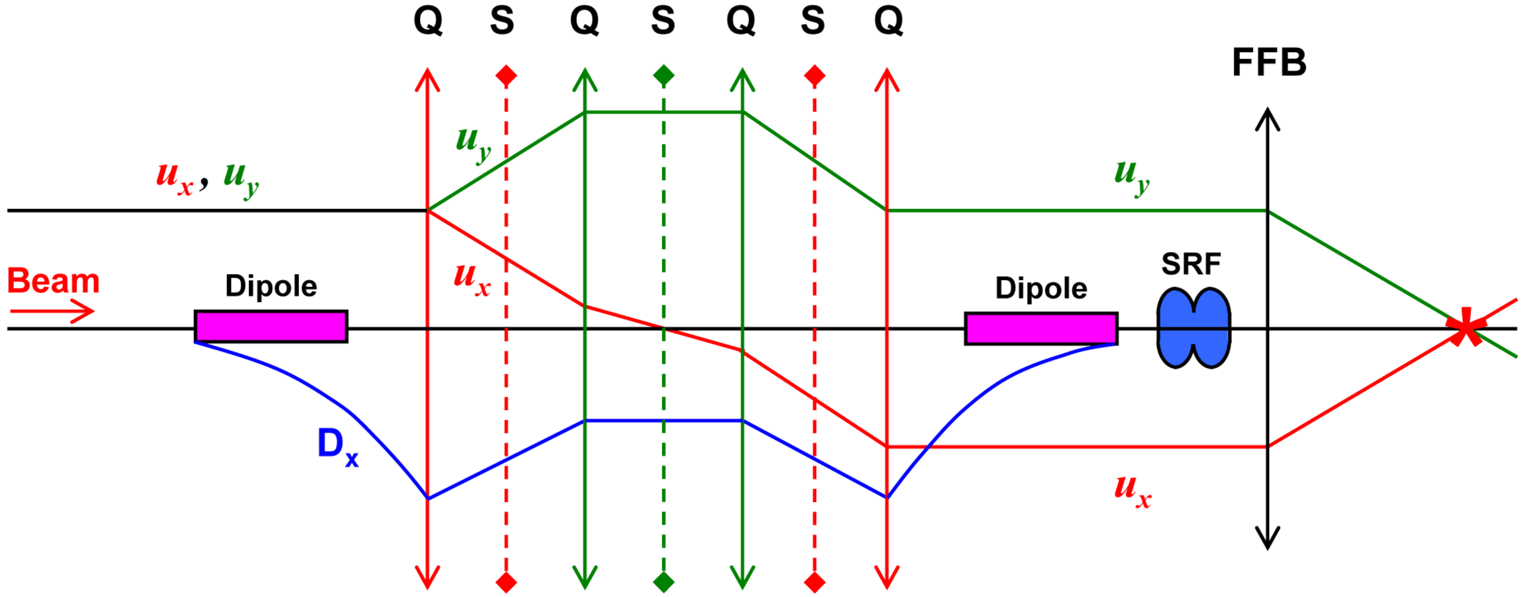


Outgoing



Chromaticity Compensation Concept

- Modular approach: IR designed independently to be later integrated into ring
- Dedicated symmetric Chromaticity Compensation Blocks (CCB)
- Each CCB is designed to satisfy the following symmetry conditions
  - u_x is anti-symmetric with respect to the center of the CCB
  - u_y is symmetric
  - D is symmetric
  - n and n_s are symmetric



Compensation of Main 2nd-Order Terms

- 2nd-oder dispersion term and sextupole beam smear due to betatron beam size

$$\int_0^* D(Dn_s - n)u_x ds = 0, \quad \int_0^* n_s u_x^3 ds = 0, \quad \int_0^* n_s u_x u_y^2 ds = 0$$

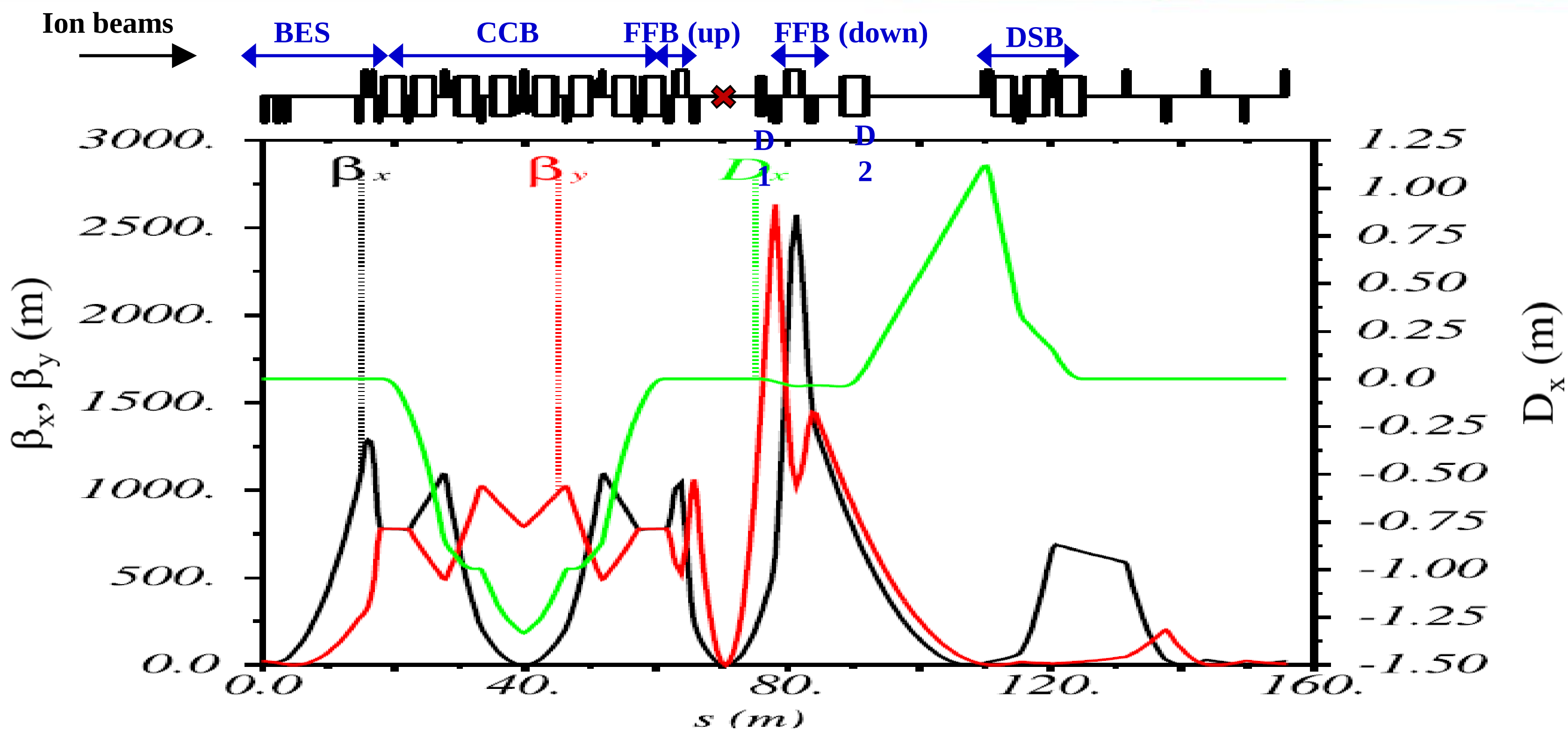
are automatically compensated.

- Chromatic terms

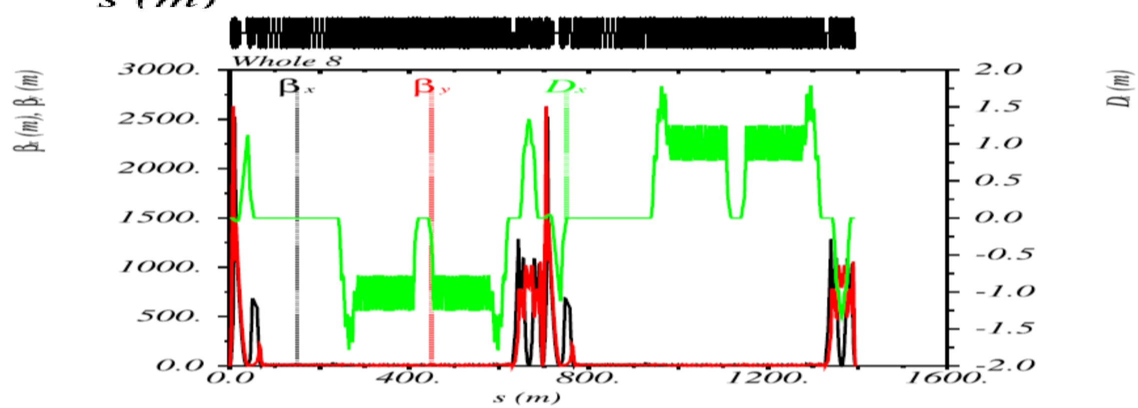
$$2\int_0^* Dn_s u_x^2 ds = \int_0^* nu_x^2 ds, \quad 2\int_0^* Dn_s u_y^2 ds = \int_0^* nu_y^2 ds$$

are compensated using sextupoles located in CCB's attaining
  - local chromaticity compensation including contributions of both the final focusing quadrupoles and the whole ring
  - simultaneous compensation of chromatic and sextupole beam smear at IP restoring luminosity

Ion IR Optics

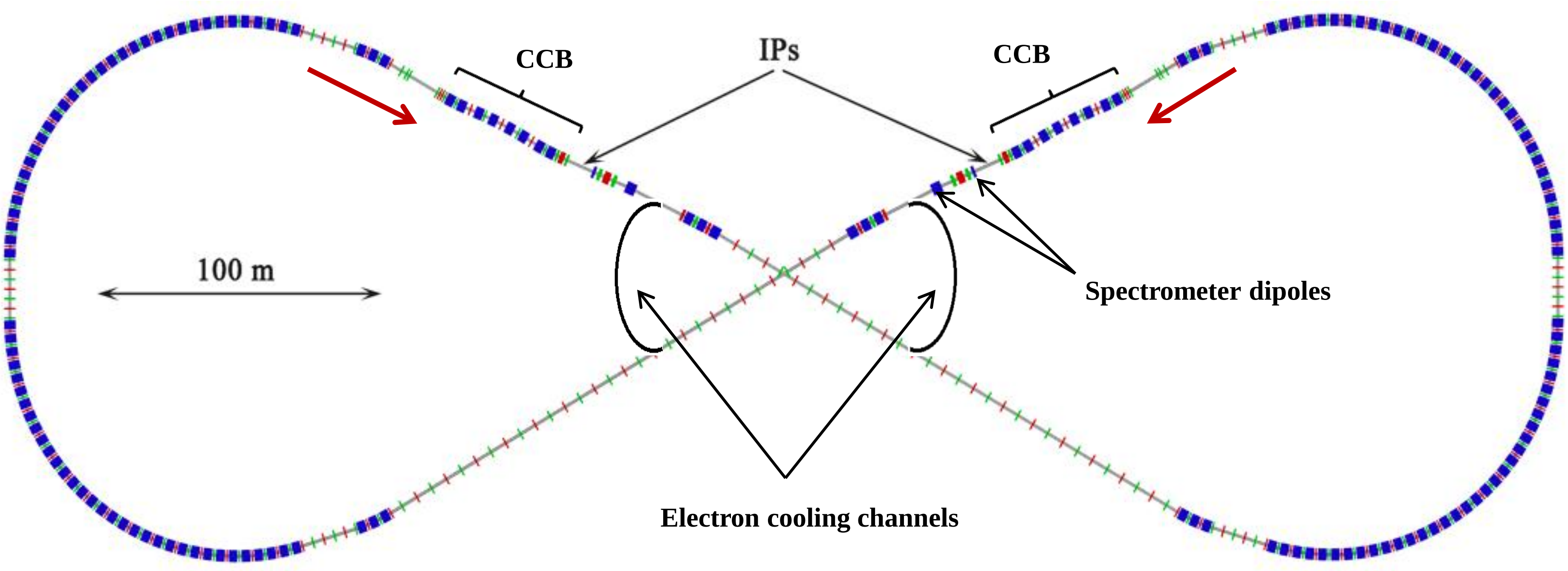


- BES: Beam Extension Section
- FFB: Final Focusing Block
- D1,D2: Spectrometer Dipoles
- DSB: Dispersion Suppression Block
- Two sextupole families are inserted symmetrically in the CCB (the shorter bar in the above lattice plot) for the chromaticity compensation



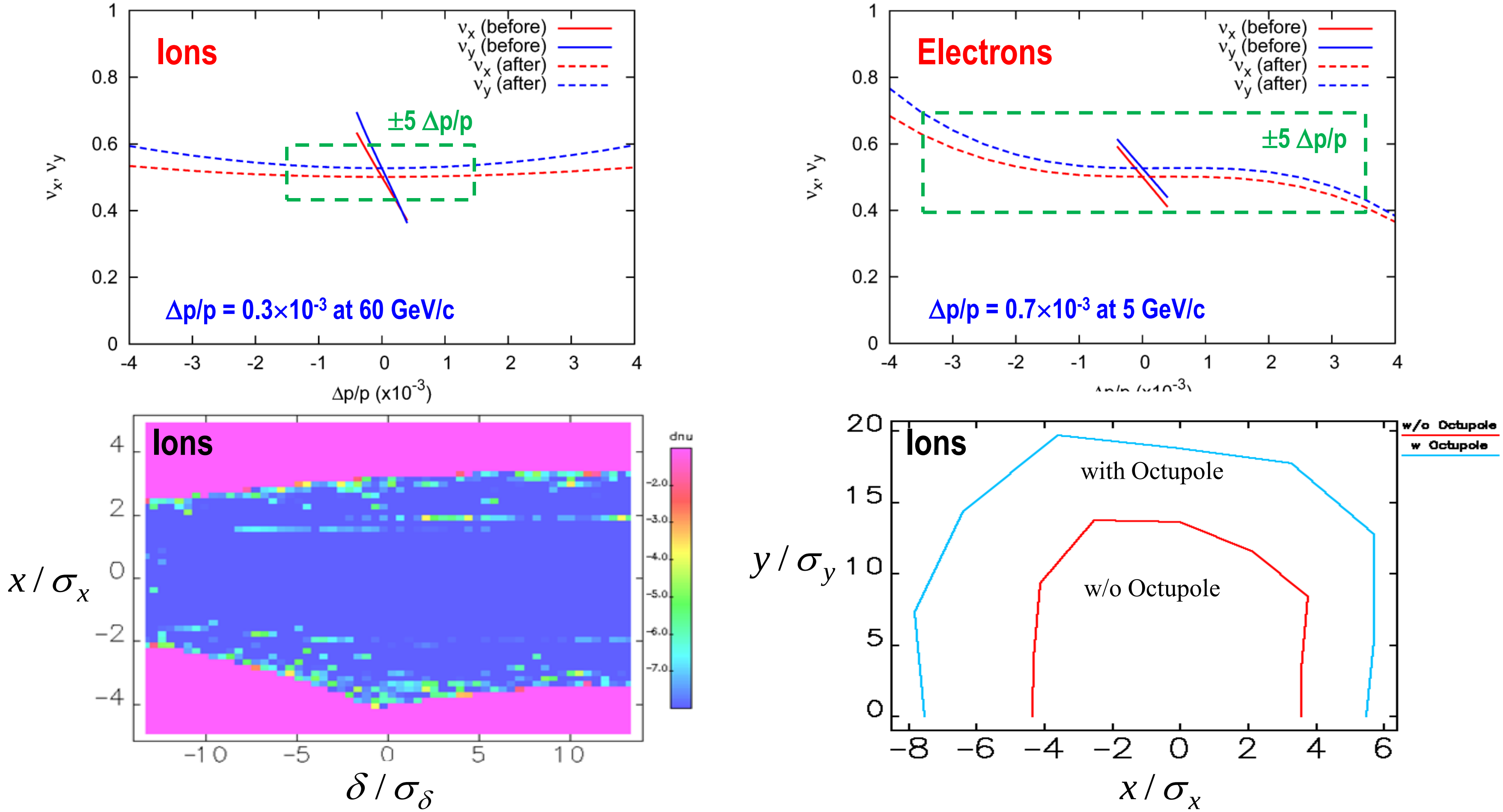
Complete Ion Collider Ring Layout

- CCB dipoles in the upstream of IPs bend particles outside of the ring
- Spectrometer dipoles in the downstream of IPs bend particles inside of the ring
- Such an arrangement leads to put the neutron detector "ZDC" outside of the ring, leaving the space inside for electron cooling channels.



Momentum Acceptance & Dynamic Aperture

- Study of simplified, yet more challenging (due to higher chromaticity) symmetric ±7 m Ion IR design
- Compensation of chromaticity with 2 sextupole families only using symmetry
- Non-linear dynamic aperture optimization and studies of error impact under way



Immediate Outlook and R&D

- Optimize the crab cavity design for the MEIC parameters
- Consider integration of the crab cavities into the collider ring design
- Evaluate multi-turn beam stability and beam emittance impact
- Evaluate tolerances on cavity amplitude and phase errors
- Estimate crab cavity impact on the dynamic aperture
- Continue the chromaticity compensation scheme design of the interaction region for both ion and electron collider rings
- Study the nonlinear characteristics of collider rings
- Develop advanced nonlinear correction schemes for dynamic aperture
- Investigate the magnet fringe field, multipole component and orbit error effects
- Develop closed orbit correction system and orbit control scheme to maintain collision

JLab EIC Study Group

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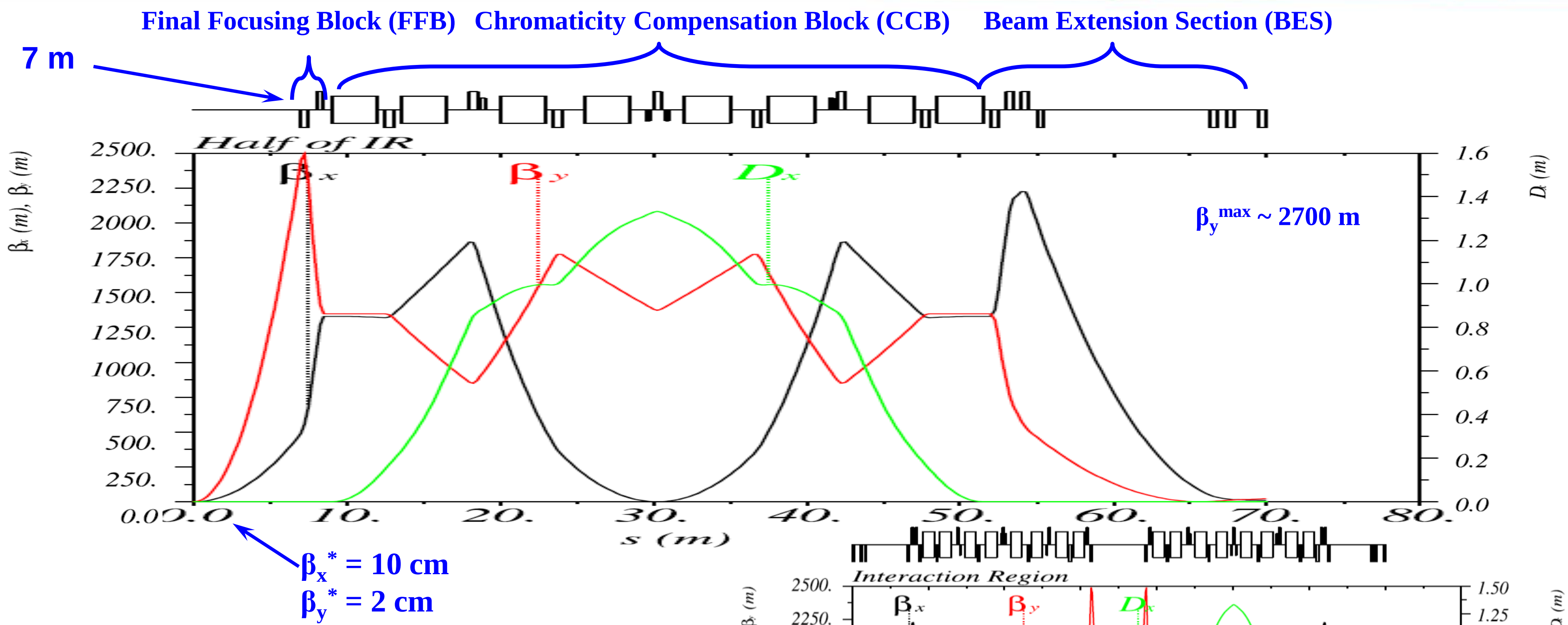
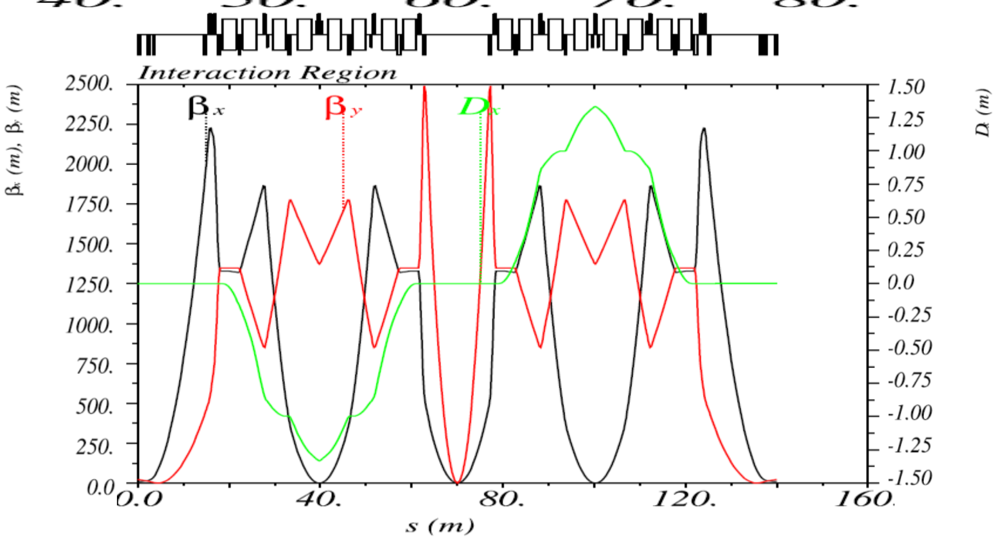
Thank you for your attention !

Back Up

Interaction region: Ions





Interaction Region Design Challenges

- Low β^* is essential to MEIC's high-luminosity concept
- Large size of extended beam $\beta_f \beta^* = F^2$
  - Chromatic tune spread $\Rightarrow$ limited momentum aperture
  - Chromatic beam smear at IP $\Delta F \sim F\Delta p/p >> \beta^* \Rightarrow$ limited luminosity

$$\Downarrow$$

  - Sextupole compensation of chromatic effects $\Rightarrow$ limited dynamic aperture $\Rightarrow$ compensation of non-linear field effects
  - High sensitivity to position and field errors